Art. XVII.—*On the Formation of Mineral Veins and the Deposit of Metallic Ores and Metals in them.* By Mr. H. A. Thompson.

[Read 12th August, 1867.]

For the purpose of this paper mineral veins may be divided into two classes—those more or less vertical, found in all metalliferous strata; and the flat or horizontal veins, most distinct and regular in the carboniferous limestone, but also occasionally found in the diorite dykes traversing the schistose rocks, or in these rocks themselves. The bounding walls of mineral veins are usually well defined, but not universally so, there being some irregularity in this respect; and the veins vary from a mere thread up to 50, 60, or even 100 feet in width. In some cases the space between the walls of the vein is filled up with solid materials—quartz in the silurian rocks, and carbonate of lime and sulphate of baryta in the carboniferous limestones; in others a portion of the space is occupied by slate, clay, or earthy matter. The ores of the different metals are found mixed with these substances, sometimes in masses without any perceptible order, at others in layers parallel to the sides of the vein, and also in the cleavage planes and fissures or joints of the adjoining rock. Veins are in some cases continuous for many miles in length, and have been worked to over two thousand feet in depth without giving any sign of closing; in others they are limited both in length and depth. Some veins retain a regular width over large areas, others open out into bunches, and then contract into mere joints at irregular intervals.

With such a diversity of conditions it is not surprising to find that there has been an equal diversity of opinion as to the mode in which these veins have been formed; but the theory now generally supported is, that they have been faults caused by some disruptive force—the fissures thus opened having been afterwards filled up with the minerals now constituting the vein. Acting on this theory, the veins of different districts have been classed in series in accordance with their presumed relative age, the latter being fixed by means of the dislocations which occur at their intersections with each other.

One object of this paper is to show that, both as regards the formation of the veins and their relative age, these conclusions have been too hastily drawn.

As regards the relative age of veins it has been held that of two veins crossing each other, where one is unbroken (*a* Fig. 1) and the other faulted (*b* Fig. 1), the unbroken vein indicates the latest fracture, and that the faulted vein has been dislocated by the sliding of the sides of that fracture. But this evidence of the relative age is not conclusive, because the faulting of the vein *b* may not arise from the sliding of the sides of the fissure *a*, but from *a* being the oldest vein, and therefore interrupting the action of the force which has formed the vein *b*, thus causing an apparent dislocation, when the deduction as to age will have to be reversed, and *a* must be considered as the oldest, not the latest fracture.

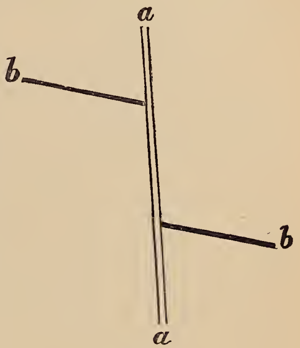


Fig. 1.

Cases are frequently met with where several parallel veins are faulted in crossing a continuous or unbroken vein; and the respective distances of the parallel veins from each other should correspond on each side of the unbroken vein if the faulting of these veins was owing to a dislocation caused by the sliding of the sides of the unbroken vein. But instances are common where this could not be the case. For example, Fig. 2 is a plan or horizontal section of the intersection of several mineral veins (*b*, *c*, *d*, *e*, *f*), with an unbroken vein *a*, where each of these mineral veins reforms at different distances from the original line of bearing; and it would be impossible to account for the faulting by the sliding of the sides of the cross vein *a*.

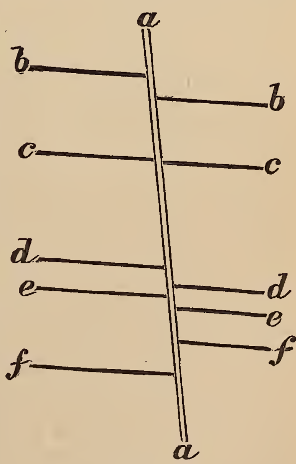


Fig. 2.

Fig. 2, Hanson Mear mine.

A like section is shown in Fig. 3, where a mineral vein *b* comes up to the unbroken cross vein *a* in one branch, and at one hundred and fifty feet to the north, passes off in three branches.

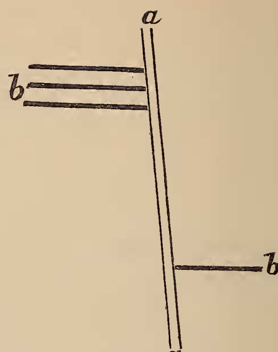


Fig. 3.

Where the shifting or faulting of the vein is due to the sliding of the sides of the vein crossed, the faulted vein will be found to curve back to the old line of bearing, as shown in Fig. 4, where the cross vein *a* appears to have been faulted a distance of eighty feet by the sliding of the sides of the mineral vein *b*.

In the examples (Figs. 2, and 3) the unbroken veins or joints have been in existence before the mineral veins were aggregated, and the continuous line of the latter having been interrupted by the unbroken vein or fracture, they have formed on joints at some distance from the original line of bearing. These are not solitary instances of the apparently faulted joints being of more recent formation than the unbroken joints.

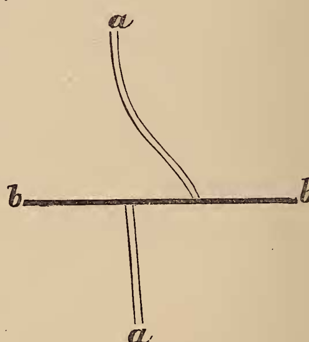


Fig. 4.

One extensive mining district in Yorkshire is traversed by a strong east and west vein, having a vertical throw or fault in some places of two hundred and forty feet, and which has been traced over thirty miles in length. This vein is not ore bearing, but at irregular intervals it has several series of veins striking off from it on each side, and bearing a few degrees more to the north, which are the mineral veins of the district; and in none of the instances coming under my notice did the veins on one side of the cross vein correspond with those on the other in their relative distance from each other, although each series was evidently the same line of mineral veins.

Whatever conclusions may be arrived at on this subject,

Fig. 3, Rampgill mine.
Fig. 4, Scaleburn mine, Foster's sections.

it should be remembered that they will not decide the comparative age of the mineral deposits in the veins, but only that of the joints on which the veins have been formed, for it is possible that these joints may have been in existence for unknown ages before they were converted into veins by the aggregation of the minerals on the lines of fracture.

The principal evidence against the theory, that veins are formed on the fissures caused by faults, and that these fissures have either been opened at once, or by successive stages, marking different epochs of disruption, and remained open until the material now filling the fissure was deposited, will be found in the veins themselves, for few cases can be produced where such a mode of formation is possible.

Mineral veins generally penetrate to a great depth, and that not vertically, but with a greater or less underlay through strata of varying character. Under these conditions it is difficult to see how a fissure a few feet wide, from one to two thousand feet in depth, and extending for several miles, could remain open for the hundreds, or perhaps thousands, of years that would be required to fill it by the slow process of deposition from water circulating in the fissure, and holding in solution the minerals now constituting the vein.

Even in hard rocks, and with only a small area open at one time, the greatest difficulty the miner has to contend with, is the keeping of the fissure from closing, by means of timber or stone-work, until the contents of the vein can be taken out; and all who have had practical experience in working mines will be aware that it is absolutely impossible for the above theory to be correct.

The pressure on the sides of the vein increases rapidly with the depth; and in many of the softer silurian rocks, where the smallest fissure would not remain open, we have large mineral veins. Take, for instance, the Old Man vein at Clunes, which is some five or six feet wide at the surface, but in going down swells out to one hundred and twenty feet wide, and then contracts again, or rather breaks up, at a greater depth. Many cases of a similar kind will be found in the quartz mines of Sandhurst, Maldon, and other parts of the colony, where the veins occasionally open out and form large bunches of quartz. Yet we are asked to believe that such huge cavities have remained open during the long period of time required to fill them.

Still greater is the difficulty of accounting on this theory for the formation of the mineral veins in the diorite dykes found in the schistose rocks. Take, for example, the Morning Star Hill, at Wood's Point, of which Fig. 5 is a cross section.

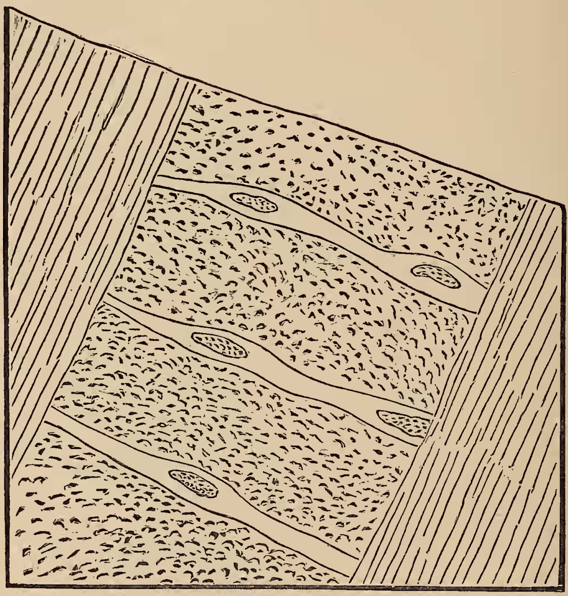
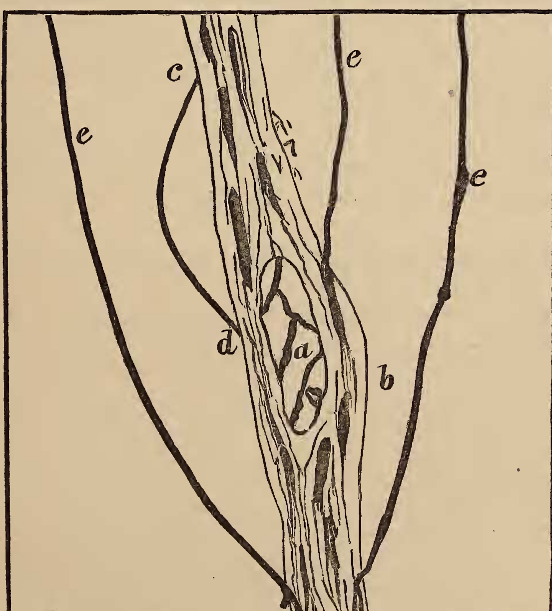


Fig. 5.

The dyke underlays to the west, and is traversed by a series of auriferous quartz veins more or less horizontal, situate one below the other, and having no connection with each other. Portions of the dyke are frequently enclosed within the vein, similar in character to the riders in vertical veins. These parallel flat veins could not have been a series of open fissures, unless the portions of the dyke between them had been suspended by the pressure of the schist on each side—a manifestly absurd supposition.

The open fissure theory might have been tenable as regards some veins, so long as it was held that the contents of these veins had been of igneous origin, for the minerals forced into the fissure in a molten state might have kept it open, as in the case of trap dykes; but when the igneous theory has been abandoned, it is inconceivable how geologists can cling to a supposition so opposed to all experience. It may be urged that when the veins were formed the rocks might have been in such a hard and compact state as to allow these fissures to remain open. There is no evidence, however, to support such an assumption, and all analogy would lead to the contrary belief. But even supposing that the rocks had at some time been so hard as to allow of open fissures, penetrating to a great depth, this theory will not account for the formation of the small detached leads and bunches of quartz found scattered throughout the silurian rocks wherever these rocks have been much decomposed, nor for the shallow gash or wedge-shaped veins which do not penetrate far from the surface. In these cases there could be no circulation of currents of water, for the quartz leads only extend a few feet, and the gash veins are closed before they reach the deep source from whence the contents of the veins are, it is assumed, derived.

The conditions under which riders (*i.e.* detached masses of the bounding rocks enclosed in the vein) occur in veins are also incompatible with the open fissure theory. Fig. 6 is a



section of a lead vein in the limestone rock, where the dark lines represent the ore in the vein, and in the strings or joints, *e e e*, connected with it. It will be seen that the

Fig. 6.—Vertical Section.

rider *a* appears to have been separated from the wall of the vein by the gradual filling and expansion of a joint at *b*. At *c d* is shown a similar joint filled with ore, where, if the deposition of minerals continued, the vein would form along the joint *c d*, and the enclosed block would be converted into a rider. Sometimes these riders remain *in situ*, in other cases they have been lowered for some distance, probably through the decomposition and removal of the constituents of the vein on which they had rested. The riders in flat veins present much the same appearance as those in the vertical veins, and have evidently originated in the same way.

To recapitulate. We have opposed to the theory that mineral veins have been open fissures caused by some disruptive force, either acting at once or by a succession of movements, and filled by the gradual deposit of minerals brought from below in currents of water circulating in the open fissures.

1st. The impossibility of any fissure remaining open, even to the smallest extent, in most of the rocks traversed by vertical or horizontal veins.

2nd. The fact that this theory will not account for the filling of the wedge-shaped veins, nor for the formation of the surface bunches and the detached leads or strings of quartz.

3rd. The phenomena attending the occurrence of riders both in flat and vertical veins.

In support of this theory instances have been adduced, where the deposit of minerals assumes the form of corresponding parallel layers on each side of a vertical central rib. But it should be noted that this is not the ordinary arrangement of the minerals in the vein—in fact, it is an appearance rarely met with, and then only in hard rocks, and extending over limited portions of the vein. The ordinary flat veins in limestone rocks may in some instances have been open cavities, or it would be more correct to say, that open cavities may have existed in some portions of these veins previous to the deposition of the ores; and similar small cavities may occur in vertical veins traversing hard rocks, but these are exceptional cases, and their occurrence on this small scale does not remove the impossibility of whole mineral veins being formed in this way.

On the other hand, nearly all the facts observed point to the gradual formation of the veins by the same law of replacement atom by atom, which causes a tendency in the constituents of some rocks to aggregate in bands or round some centre—a law still obscure, but the existence of which is now generally acknowledged. The forming of the vein fissures and the deposit of minerals in them appear to have been simultaneous operations.

It will also be found that the majority of mineral veins are not formed on faults, but either on the cleavage or divisional planes.

All rocks, however elevated they may be above the water level of the country, are more or less porous, and hold a large per centage of water.

The most compact marbles known will hold $\frac{1}{200}$ part, and ordinary limestones $\frac{1}{25}$ part of their weight of water, while Bath stone will take up one gallon, and chalk two gallons per cubic foot. Mr. S. T. Hunt has carried out a series of experiments to ascertain the amount of water that can be absorbed by the paleozoic rocks of Canada. He found that the limestones and sandstones would take up from 1 to 13 per cent., and the shales from ·75 to 7·94 per cent. of their weight of water. A bed of rock absorbing only 2·5 per cent., and one hundred feet thick, would contain 70,000,000 cubic feet of water in a square mile of area, a quantity sufficient to supply seven gallons per minute for over thirteen years.

This water is never pure, for it invariably holds different mineral substances in solution in greater or less quantity, which must excite slow electro-chemical action, intensified by the magnetic currents constantly circulating in the crust of the earth. However unchangeable the rocks may appear to our limited experience, it is certain that these forces acting during long ages have caused, and are now slowly causing, great changes. Consolidation of the particles of the rocks, alterations of their crystalline structure, aggregation of their constituents into nodules or bands, decomposition under a change of conditions of the bodies previously formed, are all forces which have been in operation from the time when the rocks were first deposited, and are now probably as active as ever. The views as to the great change thus produced in the structure of rocks are constantly being extended. Nearly thirty years ago the late Mr. Evan Hopkins called attention to instances of the gradual change of granite to gniess, and gniess to mica-schist; and from these drew the conclusion that the gniess and schistose rocks were merely changed granites.

The presence of organic remains in the schistose rocks indicated that this could not be the case, but the investigations of the English Geological Survey have shown that the observations of Mr. Hopkins were correct, although the conclusions he drew from them will have to be reversed.

The opinion that granite is only a changed form of the schistose rocks is daily becoming more general among practical geologists. Messrs. Hicks and Salter, in a report on the geology of St. David's, Pembrokeshire, read at the last meeting of the British Association (1866), state "that the Harlech group has a passage downwards into the central syenitic mass, so distinct and gradual as to induce the belief that that mass is throughout no other than altered Cambrian." Professor Hitchcock also describes an extensive bed of partially metamorphosed conglomerates where the quartz pebbles had been elongated, and in some cases had assumed a laminated structure, the elongation and lamination being in a meridional direction

Whether such is the origin of the granites or not, it must still be allowed that the slow and gradual changes at present in operation which, in the long course of ages have produced the great alterations in the physical geography of the earth's surface now observed, may have produced a like change in the rocks themselves, and unless we give due weight to the accumulative action of these small changes (*i.e.* small in a limited space of time), little progress will be made in explaining the phenomena attending the formation of mineral veins.

The silurian and other rocks, besides the planes of deposition, commonly called bedding or sedimentary planes, are traversed by vertical cleavage planes, and these are again crossed by joints or divisional planes at different angles, which penetrate to a great depth. The ordinary rock-joints are usually confined to the bed in which they occur; it is not these, however, that we have to consider, but only the large master-joints of a district which traverse all the beds. Although the direction of these divisional planes is variable, yet series of them running on parallel lines are found in sufficient numbers to show that they owe their origin to some general cause. I have seen large areas of flat limestone-rocks on the shores of Northumberland, where the divisional planes crossed each other with such regularity as to present the appearance of a gigantic tesselated pavement.

Mr. Hopkins has tried to demonstrate mathematically that a series of joints would be formed parallel to an axis of elevation, along with a second series crossing the first at right angles; but this theory must be put to the test of a searching comparison with the observed phenomena in numerous instances before it could be accepted as the true explanation, and this has not yet been done. In the case of the partially-metamorphosed conglomerates described by Professor Hitchcock, the bed was crossed by east and west joints or divisional planes, cutting smoothly through the pebbles; these planes having in some places polished faces, although the cut pebbles on each side of the joints exactly corresponded, showing that there had been no slip. He considered mechanical agency could not possibly account for these phenomena, and that we are driven to the supposition that some polarising force has been the agent.

It is indeed difficult to conceive how these regular series of parallel joints or divisional planes could be produced by disruptive forces acting from below, and so far as the cleavage planes are concerned, the prevailing opinion is that they have been caused by polar forces originating with the magnetic currents traversing the earth. It is true that laminations similar to cleavage planes may be produced by lateral pressure; but this will not account for the constant meridional direction of these planes, and has no bearing on the formation of divisional planes.

Mr. Fox's investigations into this subject are well known, and the repetition of one of them by Mr. Hunt of the School of Mines, Jermyn-street, appears to bear so exactly upon the question, that it may be well to briefly describe it. The apparatus used was an oblong box or trough, and the material operated on was Stourbridge clay, plaster-of-paris, bath-brick, sandstone, and powdered coal. The trough in this experiment was divided into two compartments by a wall of clay three to four inches thick, and on one side of this wall was placed a plate of copper, on the other a plate of zinc; the two plates being connected together by a strip of copper. The cells were then filled with the exciting fluids, that on the copper side being a weak solution of sulphate of copper, and on the zinc side of the muriate of soda. A complete circuit was thus formed, the current passing from the zinc plate along the strip of copper to the copper plate, and from the latter through the wall of clay to the zinc plate. The action was kept up for six months by daily additions to the solutions, when the clay wall was examined and found to have assumed the conditions described by Mr. Fox. On the side next the zinc plate, the clay was traversed by distinct lines of cleavage parallel to the sides of the clay wall. On the copper side, instead of the vertical laminated structure, there was a consolidation of the mass; this consolidation appearing to take place in the direction of the current; the induration in many places being very striking, and the fluid and clay were considerably elevated on that side. This action produced a hollow in the centre of the mass, and a series of curved lines proceeding from the top of the zinc plate towards the centre of the copper plate, and from thence back towards the bottom of the zinc plate. As these curved lines approached the zinc side, they were crossed and split by the vertical laminations, although very distinctly continued. A dark band was formed on the curved lines, and in this near the copper plate laminæ of copper were found, while at a greater distance from the plate the metallic copper in the laminæ was replaced by carbonates of copper and zinc. A number of nodules were also formed on the lines of the magnetic currents.

This experiment indicates that two forces or lines of power were in operation; one of them producing cleavage laminations similar in character to those traversing the schistose rocks, the other exerting a drawing action towards the copper plate; elevating the clay on that side and leaving a cavity in the centre. At the same time a molecular change of structure was going on, as indicated by the formation of nodules in the clay; and not only were the metals employed removed and deposited in the laminations of the clay, but by the same agent the *ores* of these metals had been formed and deposited on the laminations under the same conditions as they are found in mineral veins.

If on this small scale, and in such a comparatively short period of time, these effects can be produced, it is easy to conceive how powerful may be the action of magnetic currents circulating in the crust of the earth—how readily the phenomena we now observe may be produced by them—and how varied these phenomena may become through the disturbing influence of peculiar local conditions. It is probable that here we have the principal agent in the formation of the cleavage and divisional planes, and not unlikely that the magnetic tension may have at least assisted in the opening of vein-fissures in the harder rocks.

I have met with one instance where the rock on the north side of the vein presented a singular appearance, which might arise from this cause. At the Beldi hill mine—an east and west vein in the mountain limestone formation—a drive was taken into the north wall in the twelve fathom lime; on the wall of the vein the rock was hard and difficult to work, with a peculiar knotted appearance as if it had been compressed by some enormous force, and the drive was carried several fathoms before the limestone resumed its usual character. A lower drive was carried in the same direction in the plate or shale beds underneath the limestone. These beds are nearly horizontal, and the sedimentary planes correspond; but on the north wall of the vein there was a vertical cleavage which had nearly obliterated the sedimentary planes, and as in the limestone drive above, the bed only attained its ordinary character at some distance from the vein. The compression of the sedimentary beds in the schistose rocks when these beds are at right angles to the cleavage may possibly arise from the same cause. In numerous cases, however, the conditions point more to the gradual replacement of the rock by the constituents of the vein, and the force of tension could only have acted as an auxiliary. For instance, a mineral like quartz distributed through a mass of alumina, as it is found in the schistose rocks, has a tendency to segregate itself from the clay and accumulate on certain lines or points, where it will replace the previously existing rock atom by atom by an action similar to that by means of which pseudomorphic crystals are formed. An interesting experiment bearing on this point is described by Becquerel:—A plate of steel was enclosed in a case communicating through a fissure at one end with a weak solution of nitrate of silver—kept at the same level by occasional additions to the solution—and left in this state for eight years. At the end of that time it was found that one half of the steel plate was changed into very pure silver, the volume of silver being the same as that of the steel removed.

After a careful analysis of the observed facts I have come to the conclusion that mineral veins have not been open fissures caused by faults in the sense usually understood, but that they have formed gradually on the existing joints, irrespective of whether these joints were cleavage planes, divisional planes, or true faults.

The lower silurians of this colony are highly metamorphosed rocks, exhibiting the marked cleavage which usually attends the change from a compact crystalline structure to a comparatively soft state, and in these rocks the quartz veins have generally formed on the cleavage planes ; but in the rare instances where they have formed on the divisional planes, they have usually been exceedingly productive.

In the upper silurians, where the cleavage is imperfect and when present seldom extends over large areas, the veins generally form on the divisional planes, or on some fault or dyke. In consequence they are, as compared with the veins of the lower silurians, more apt to form rich deposits of surface quartz, which are soon exhausted, as they are not continuous either in length or depth. Wherever they are of a more permanent character, it will be found that a change has occurred in the rocks bounding the vein similar to that observed in the lower silurians.

Where these upper silurians are traversed by thin diorite dykes, the auriferous quartz veins usually form on the side of the dyke, in the same manner as the lead ore veins have formed on the side of the trap dykes in the island of Islay.

In the wide diorite dykes the quartz veins frequently traverse the dyke itself, either as flat or highly inclined veins, or as irregular leads of quartz.

The next point to be considered is the mode in which the contents of the veins have been deposited, and the source from whence they have been derived :—

In discussing this question occasional reference will be made to the phenomena observed in the veins of the carboniferous or mountain limestone of the north of England. This formation consists of a series of nearly horizontal alternating beds of shales, sandstones, and limestones, and in the Derbyshire mining field, of alternate beds of limestone and basalt. In some of the limestones flat veins are formed, but generally the veins are nearly vertical, and thus afford an excellent opportunity for studying their changes of character as they traverse and are affected by the different beds of rock. Had more attention been given to the veins of this formation, a clue would have been obtained to the phenomena attending veins in the silurian rocks, and correct views would have been sooner promulgated as to the agents employed in collecting our metallic treasures.

For some time the question as to whether the contents of veins were of igneous or aqueous origin created much discussion. This may now be considered as set at rest, the presence of undoubted aqueous deposits in veins in large proportions rendering it more than probable that all the contents are of this character. For example, there can be no question but that the quartz found in the veins of this colony is of aqueous origin. Bischof in the first instance, and Dr. Percy since, point out that although quartz may be formed artificially both by igneous and aqueous means, yet there is a difference in the specific gravity of the two minerals thus obtained, that of the igneous quartz being 2·1 to 2·3, of the aqueous quartz 2·5 to 2·6.

The quartz met with both in mineral veins and in the granites has the specific gravity of aqueous quartz, and may therefore be safely considered as having been formed by aqueous action, and not by fire. This view is further supported by the conditions attending these deposits, for on no other hypothesis yet advanced is it possible to account for the cases frequently met with of a change from pure quartz to quartz-rock, sandstone, and slate, so gradual as to render it impossible to draw a boundary-line between the different deposits, or for the surface veins and detached strings or leads of quartz, which are found throughout the lower silurian rocks, and have no connection with any fissure or opening through which the molten quartz could have been injected.

Change is no doubt going on in mineral veins as it is in all other deposits, and the contents may have been frequently removed and replaced, as is indicated by the presence of pseudomorphic crystals of different minerals. The same agent that collected the minerals in the veins may re-arrange them, or even carry them away altogether, and it is in this way that cavities have probably been formed in the veins traversing the limestones, and where the walls were of hard rock, or where they had been left coated with solid mineral deposits, so as to allow the cavities to remain open, the space may have been filled in with the earthy matter and ore now found in some veins, or with the regular crystalline deposits seen in others. During these changes, the corresponding vertical parallel ribs of minerals occasionally met with in veins may have been formed, and it is even possible that veins may have been partially or wholly obliterated. Bischof mentions a case where a previous deposit of fluor and calc spar had been removed from a whole series of veins, and replaced by an equal quantity of quartz.

The deposit of metallic ores and metals in the veins has been ascribed to various causes, of which the principal are—

1st. Injection of the ore or metal into the vein in a molten state.

2nd. Deposition in the veins by the sublimation of substances driven by heat from beneath upwards.

3rd. Deposition of ores from solutions in water, brought from below.

4th. Deposition or rather aggregation in the veins of ores or metals derived from the bounding rocks.

The three first theories are founded on the opinion that the metallic ores and metals found in the veins are derived from some deposit situate at an unknown depth below the surface of the earth. The fourth that they have been derived from the rocks bounding or immediately contiguous to the vein, and have been aggregated in the latter in the same way and by the same power which has collected the other mineral constituents of the vein.

The first supposition assumes that the ores and metals have formed a portion of some molten mass, and have been injected into the veins. It is hardly necessary to dwell on this theory, the conditions under which the sulphides, carbonates and oxides of the different metals are found rendering it impossible that they can have been deposited in a melted state, while the peculiar arborescent and crystalline form of the native metals in veins—so completely different from the rounded figure which melted metals assume—and their frequent presence as fine flakes like gilding in the cleavage planes of the rock adjoining the veins, afford sufficient proof that they have not been deposited in this state.

The second theory is more probable, inasmuch as some of the metallic ores can be formed by sublimation—a fact proved by their occasional presence in the flues of smelting furnaces—yet to render this theory possible it must be assumed that molten masses of ore exist in the interior of the earth; or rather, as there are several metals usually found in each vein, there must be a corresponding number of melted parcels of the different ores, and these must each have communication with the vein. But there are many productive veins which do not penetrate far from the surface, and the flat veins of the diorite dykes and the mountain limestone formation, could not have obtained their ores in this way, for there is no passage or communication to connect them with the hypothetical deep storehouse. Most veins are also saturated with water, the quantity increasing with the depth, and it is difficult to see how the sublimed ores could penetrate this water for many thousand feet, instead of being deposited as soon as it reached the water, which we know always is the case in smelting works.

Again, in the Derbyshire and north of England mining fields, where the veins traverse horizontal beds of limestone, sandstone, shale, and basalt, if the ores were deposited by sublimation, they would be distributed indifferently throughout these beds; but it is found that the veins only carry ore while traversing a certain number of these rocks, while in the remainder they are invariably barren. In the mines of the silurian formation the same phenomena may be observed. A change in the character of the bounding rocks usually affects the ore-bearing qualities of the vein, and where the latter pass from the schist into the granite there is frequently a change in the metals aggregated, as from copper to tin, or the contrary.

Similar difficulties have to be overcome in endeavouring to apply the third theory. As regards the vertical veins it has been suggested that the magnetic condition of some of the rocks influences the deposition on them of the ores brought from below, and held in solution in the water circulating in the vein. In the mountain limestone the productive character of many of the beds varies within short distances, although constant in a certain area, while no perceptible difference can be detected in the character of the rock. This is not a convincing refutation, for there may be a change in the magnetic condition of the rock without any visible alteration in its appearance; but the difficult task still remains of accounting on this hypothesis for the filling of the flat and wedge-shaped veins, the deposit of minerals in the detached strings of quartz, or for the metallic ores intimately incorporated with the rocks. In driving levels in the mountain limestone, I have met with small cavities in the solid compact rock not connected with any fissure or joint, and yet these cavities were filled with galena.

Copper ores are found disseminated through some of the old red sandstone beds in Ireland, and in the so-called copper slates of Germany.

Tin ore is also found so intermixed with the granite as to render it profitable to quarry and crush the surface rock in many places.

The stream tin of this colony, and most of the gold associated with it, appear to have been derived from the decomposition of the granites in the neighbourhood of which they are found.

The obstacles enumerated have been felt even by the staunchest supporters of the above theories; and it has been suggested that deposition from sublimation, from currents, and from the bounding rocks, may have been going on at the same time. It is not probable, however, that nature is working by several distinct means in filling the veins; and if it is found that the theory of deposition or aggregation from the bounding rocks will account for all the phenomena observed, and as it is the only theory which will do so, it may be safely accepted as the correct explanation of the mode in which ores have been deposited.

No doubt, in localities where powerful volcanic action is going on, metallic ores may be deposited from sublimation in sufficient quantity to afford cabinet specimens. And the veins acting as channels for water holding minerals in solution an occasional deposit may occur in this way, or a transfer of the ore from one part of the vein to another, or even to joints or veins adjoining it, may be effected. But a close examination of all the phenomena attending the deposits in veins leads irresistibly to the conclusion that the great bulk of the metallic ores have been derived from the bounding rocks.

In the experiment carried out by Mr. Hunt metallic copper and carbonates of copper and zinc were deposited along the curved laminations in the clay wall, forming in fact an artificial mineral vein. In the same way Mr. Fox obtained deposits of peroxide of tin and other ores, and proved that long-continued electro-chemical action with weak currents is able to overcome strong affinities, decomposing some bodies, and forming new combinations. Using the same agents, Becquerel has produced crystals of the sulphides of tin, copper, lead, and iron, and oxides of copper and zinc; and there can be no reason why the same minerals should not be produced by the same agents in the laboratory of nature as well as in that of the chemist.

In nature will be found all the requisite conditions operating on a grand scale. Magnetic currents traverse the rocks capable of exciting the necessary action, and bearing along with them the various metals—no such thing as dry sedimentary rocks exist naturally—for they all contain a certain amount of water, which fills up their pores, and affords an ample medium for the decomposition and transport of minerals—a road along which they may travel great distances. That this road does not remain unused is proved by the recent deposits of ore sometimes found in old mining works.

A marked instance came under my notice at the Tees-side mine, where there was an old level driven on the vein in the limestone rock, which had not been used for nearly sixty years. In one part of this level a crop of carbonate of lead was formed, growing out of the old underlay wall of the vein in long, delicate, needle-like crystals. Had the growth gone on at the same rate, the wall of the vein would have been covered with a sheet of carbonate of lead about an inch thick in the course of a few hundred years. This is far from being a solitary case, as there are few men having much experience in practical mining on old fields who could not recount similar instances of modern deposits forming in old workings. These recent deposits of metallic ores could not have been indebted to sublimation for their origin, nor to currents of water circulating in the vein fissure, as the water had been drained off by the level. It must, therefore, be evident that they could only have been derived from the rocks bounding the vein.

Coming to the gold deposits of this colony we have modern auriferous pyrites of recent date formed in the gold-bearing drifts, and the experiments, particulars of which have been communicated to the Society by Messrs. Wilkinson and Newberry, indicate how this has been effected.

These views, as to the source from whence the ores have been derived, receive strong support from most of the phenomena presented by mineral veins.

The veins in the limestone rock are usually accompanied by strings (joints filled with ore) passing out of the vein, and coming back to it after they have run a greater or less distance. (*e e*, Fig. 6.) Sometimes a portion of the wall of the vein is traversed by these joints of ore, set so close together as to render it profitable to work; and the riders are frequently of the same character, the ores in some instances being intermixed with the compact rock, in others collected into a net-work of strings. In the north of England the beds in which the veins bear ore are generally separated from each other by long intervals of barren rock, and in Derbyshire by thick beds of basalt.

Many very productive veins are met with which only penetrate a short distance from the surface of the earth.

Flat veins are formed between the layers of limestone beds, and are frequently very rich. The galena deposit of Wisconsin, in the United States, is of this character; and in many places is so regular as to allow of its being worked in the same manner as a coal seam.

The flat veins of quartz in the diorite dykes do not penetrate to any depth, and are really detached strings of quartz having no connection with each other.

Detached masses of metallic ores are found in the cavities formed in hard crystalline rocks, when these cavities are not connected with any joint.

Bands of granite are found impregnated with metallic ores, and these ores are also found disseminated in sedimentary strata.

Recent deposits of ore have been formed in old workings, where they could only have been derived from the rocks bounding the vein.

It will be seen how impossible it is in some of these cases —how improbable it is in others—for the minerals to have been derived from some source deep in the earth, and to have been brought to the surface and deposited in open fissures, either by currents of water or by sublimation.

On the other hand, how readily all the observed facts may be accounted for by adopting the theory which derives the mineral contents of the veins from the rocks bounding them, and assumes these contents to have been deposited on the joints or fractures of the rock, which have been enlarged by the aggregation of the minerals in them, operating by the law of replacement whose action is so marked, and perhaps in some instances assisted by the magnetic tension. If a steel plate can be removed atom by atom, and each atom be replaced by a corresponding atom of silver—a fact established by direct experiment—it will be readily seen that a mineral vein may be formed in the same way.

Further evidence in support of this theory will be discovered in the fact that productive veins are rarely found in hard crystalline rocks, unless a portion of these rocks has undergone decomposition. Bischof has noted this, and points out that "the removal of the constituents of a rock is always preceded by its decomposition, and is facilitated by the advance of the decomposition. Whenever quartz exists in lodes, the adjoining rock is more or less converted into kaolin, so that we find in the one place what is deficient in the other; and when it is found that the abundance of ore in a lode is proportionate to the extent of the decomposition of the adjoining rock, this circumstance can only be regarded as a consequence of that decomposition."

This peculiarity may be noted even in the lower silurians of the western gold-fields of this colony, greatly changed as these all are; but it is most marked where these rocks are hard and crystalline, as in some of our mountain ranges, or in the upper silurians; for in the latter the cleavage (which is one indication of this decomposition) is imperfect, and only extends over limited areas, and in consequence the veins formed in them have a corresponding character. When this decomposition has not penetrated far from the surface, the veins will soon die out, or become worthless; but when the decomposition sets down to a great depth, the veins will do so likewise, and are as likely to bear ore below as at the surface. Auriferous veins are only an apparent exception to this rule, for although the rock may be rich in gold, yet the latter may be prevented from collecting in the veins, because a considerable portion of it has already been aggregated in the rock, and requires a second decomposition to liberate it. Cases may therefore occur where there has been a sufficient metamorphosis of the schists to allow of large quartz veins being formed at great depths from the surface, while the bulk of the gold may still be retained in the bounding beds.

This apparent incongruity may be easily explained:—In assisting the decomposition of the rocks and the aggregation of its constituents in the veins, water no doubt acts an important part, and with the exception of gold, the veins are found to be as productive in metals at some distance below the water line as they are above that point. But this is not always the case with auriferous quartz veins. Gold is generally found intimately associated with the sulphides of iron, being aggregated along with them, and in auriferous strata the iron ore, whether collected in the quartz veins or scattered in detached crystals through the rock, is seldom found without gold. This intimate association also exists in the case of the recent pyrites formed in the auriferous drifts, which invariably contain metallic gold incorporated with the sulphide of iron. The same affinity may be illustrated by placing a piece of quartz containing iron pyrites in a weak solution of chloride of gold, and adding any organic substance, when a deposition of gold occurs on the pyrites, but none on the quartz. In many places the total amount of this ore in the schists is very great, and we can understand what a large quantity of gold may be locked up with it. Still in localities where the sulphides of iron are not plentiful, or where the decomposition of the rock has been so great as to allow a considerable proportion of these auriferous sulphides to be removed and aggregated with the quartz, rich gold-bearing veins will be found below the water line, irrespective of the depth.

When the sulphides in the rocks are completely decomposed, as they are found above the water line and near the surface, the gold thus liberated is then in a condition to be acted on by other agents, and it is probable that nearly the whole of it has been accumulated in the veins, forming the rich surface deposits so frequently met with. The rich casing or layer of auriferous slate running by the side of the quartz, which is occasionally found above the water line, changes below that point into a layer of slate full of auriferous pyrites, and an extension of this action to the bounding rocks will account for the surface deposits.

A similar illustration is afforded by the diorite dykes of the Wood's Point district. Near the surface these dykes are much decomposed, and in this condition the quartz veins traversing them have yielded large quantities of gold; but as the rock becomes hard and compact at a greater depth, the gold in the veins decreases, indicating that this decomposition of the bounding rock and consequent liberation of the contained gold, was necessary to the aggregation of the latter in the quartz veins. The dyke may contain quite as large an amount of gold where the quartz veins are worthless as it does where they are rich, but it will require long ages to pass over before the necessary changes are effected that would render this gold available.

The question as to the agency by means of which the metals were first disseminated through the rocks is not of such practical importance to the miner as that of the formation of the deposits from whence our mineral wealth is directly obtained. Mr. S. T. Hunt, who has carefully investigated this matter, expresses an opinion that the metals have been brought to the surface in solution, and precipitated by the agency of organic matter along with the contemporaneous sediments, which gradually consolidate into rocks. It is well known that both gold and silver are found in sea-water, and under favourable conditions deposits of those metals may still be going on in some of the rocks now forming at the bottom of the ocean.

It would be impossible to detail in a paper of this kind the number of minute observations made extending over many years, and forming a strong chain of evidence leading up to the same deductions. I have therefore endeavoured to lay before the Royal Society an outline of the views I have formed on this subject—one of some scientific interest, and of great practical importance to this colony—partly with the hope of inducing other labourers to enter the field. Whatever advance may be made will not be due to investigations conducted in the closet only, but it must in a great measure depend on the careful and intelligent noting of the facts observed by those engaged in practical mining.

At present these observations only add to individual experience, and unfortunately pass away with the individual; but if some system could be adopted for collecting and arranging the facts noted by different observers, say some plan similar to that by means of which Maury has given such an impulse to navigation, I believe an equal impulse would be given to our mines, through the greater certainty a knowledge of the laws which govern the deposition of metals would give to mining enterprise.

It may even be worthy of consideration whether a section of this Society might not be usefully employed in carrying out some plan of collecting and arranging the observations now lost.

Art. XVIII.—*The Ethics of Opinion and Action.* By H. K. Rusden.

[Read 9th September, 1867.]

Mr. Chairman and Gentlemen of the Royal Society,

It may be considered that I owe you some apology for venturing to ask your attention to a paper in the form of that which I am about to read; as it is in fact, simply a critique upon an article in *Frazer's Magazine*. Still though only a review, it contains as quotations all the salient portions of the essay criticised; and I think that the mode